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Reservoir Model Visualization Using 3D Printing

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ABSTRACT

Tremendous progress has been made in the last few years in reservoir modelling especially in the development of methodologies to better visualize reservoir models and in development of software that go with it. Be they simple analytical models or complex grid numerical models, all reservoir models are expected to provide vital resource information and to have the capacity to be queried to reveal more than is obvious to the professionals using them. Quite often they are expected to delineate resources and offer inferences that usually have a bearing on present and future development plans. These models are known to raise great debate among professional geothermists, developers, government and even financiers who are critical stakeholders in geothermal resource development. Reservoir models are therefore extremely useful as a strategic tool as well as a resource management tool. Rarely does all the professionals developing the resource present their datasets in the same formats. Each discipline commonly has its own set of analysis software that is separate from the other. Ironically, the stakeholders in development of the resource always need a singular unified understanding of resource potential, characteristics and performance. In the last decade, a great deal of progress was made in unifying the different datasets and in interpreting them into a singular integrated model. The need therefore arose to visualize these datasets together and offer informative images of the reservoirs that are in a sense all-inclusive but at the same time simplified to make sense to all stakeholders.

This involved development of new software with the ability to combine all the different datasets into a singular model and visualizing them all together in one space. These have led to ease of comprehension and insightful interpretation that are more acceptable among professional geothermists, developers, governments and financiers. In this paper we present a novel approach to better visualize 3D reservoir models both digitally and the emerging 3D printed models with superior visualization capability for reservoir characteristics and performance.

1. INTRODUCTION

In recent times, geothermal reservoir modelling has grown tremendously. The growth has matched growth in computing power as well. The main focus of recent developments has been the area of visualization of reservoir properties. Emerging in this growth is the need to train a 2-D dominated industry to think, see and comprehend 3-D imagery almost entirely presented in 2-D space.

Reservoir modelling involves the use of different kinds of datasets often collected over long periods of time usually several decades, in different data formats, and by different generations of staff and for various purposes. The chief aim in modelling geothermal reservoirs is incorporating and unifying the data into a singular cohesive reservoir model.

To effectively model multi-disciplinary data has been a great challenge until recently. The challenge begins in the data itself. The many different formats in which the data itself is stored/captured requires skill, time and computing resources to format and jointly interpret for a cohesive reservoir model. Although tedious, the modelling approach is inspired by the tremendous clarity that different datasets bring to conceptual modelling of a geothermal reservoir. A case in point would be that permeable zones can be looked at in light of the chemical or thermal properties of the fluid they carry. These can be jointly visualized to determine well casing designs for possible case-off of productive zones with undesirable fluid quality. To effectively interpret these datasets and to visualize them together is no mean challenge.

The next frontier of advancement in reservoir modelling is in the visualization of 3-D models created by multi-disciplinary datasets and possibly even incorporating the fourth dimension being time. The ambitions being to unify all these datasets into a singular model with capability to jointly interpret the datasets and unify a common usable visualization for high-level management to make a decision on drilling sites, production schemes, additional capital investments etc.

It is important to note here that no single modelling platform has all these capabilities inherent. Therefore, use of several different software programs is inevitable.

2. THE LIMITATIONS OF 2-DIMENSIONAL VISUALIZATION

The majority of geothermal properties are presented in different kinds of maps or graphical plots. These interpreted measurements are usually limited to two dimensional views only. But the “true” reservoir distribution is always 3- to 4- dimensional. In fact, when professionals in the geothermal industry look at a 2D map of a reservoir property, they would begin thinking about its distribution in depth or time. This is essentially an additional dimension. This “N-1 dimensionality problem” is therefore a hard reality of the industry however limiting it is.

With large numbers of wells like the case of Olkaria, in Kenya with about 400 wells, it gets increasingly difficult to fully visualize the distribution of a given reservoir property in 2-D. (See an example in Figure 1).

The thrill of observing the same properties in at least two dimensions and depth is priceless for most operators of geothermal fields. The 3-D picture gives a more complete perspectives of the geothermal resource that cannot be paralleled.

It is extremely useful to map drilling targets and to continuously monitor reservoir characteristics and production response with the third and fourth dimension where such data is available. Effectively, modelling has experienced a paradigm shift from an exploration and specialized field and become more useful to all professionals in the business.

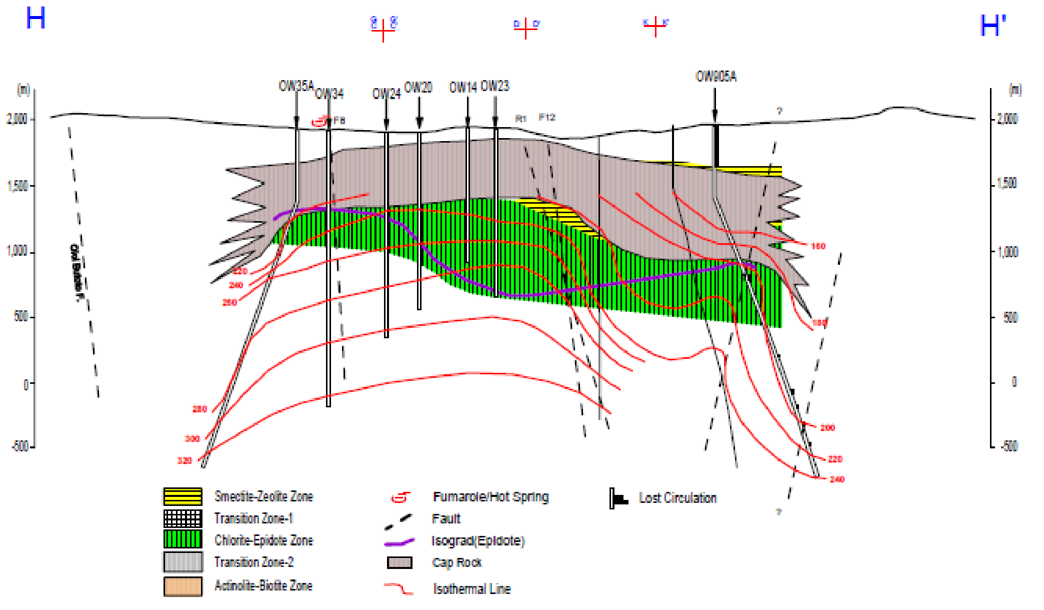

Figure 1: A simple 2-D reservoir model of Olkaria, (adapted from WestJec, 2009).

More recently reservoir models have become entirely 3-dimensional giving the operator an easy and comprehensive view of the reservoir at minimal cost. It has added new impetuous among technical crews to explore more alternatives to site new production or reinjection sites as well as understand and interpret observations made after drilling. See an example in Figure 2 where different reservoir characteristics observed in well logs are visualized jointly.

In our experience, the idea of viewing it in more than a 2-D map or plot promotes quality conversations among the work groups which often lead to better resource decisions.

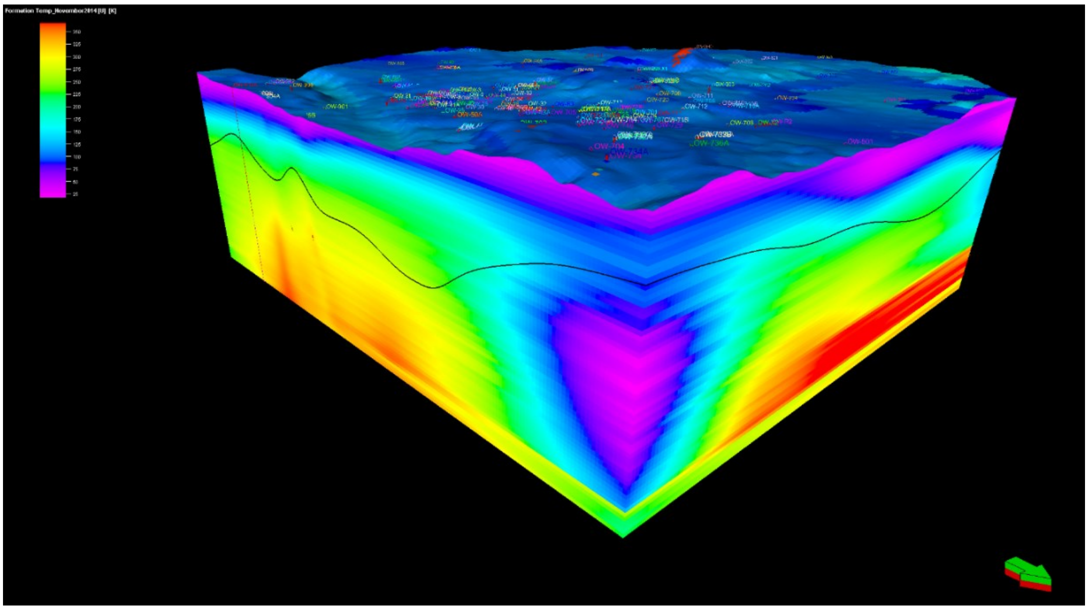

Figure 2: An example of a 3D reservoir model of Olkaria, (Saitet, et al., 2016a).

3. THE STATE OF THE ART

In in this section and summary of the state of the art of reservoir visualization today is discussed. It is intended to reveal the progress so far made in the industry with specific examples cited from previous work done by the author for Olkaria geothermal system. The conceptual model of Olkaria geothermal field is developed in 3-D digital form with a robust system of continuous visualization, cross/joint interpretation with Schlumberger's Petrel E&P software platform. The data once collected, analyzed and interpreted is input in the Petrel Modelling and Visualization Software system where it is either jointly interpreted with other datasets or visualized in 3-dimensional grids jointly with other datasets either from the same discipline or another.

For high level data visualization, a selected few model results are then 3-D printed for easy access and comprehension outside the modelling software and by management.

3.1-Dimensional Combinations

The Petrel modelling system always works in a 3-D grid with depth as one dimension. Once a grid is created with the desired architecture at the surface it is then extended to the desired depth. A constraint to the choice of depths is the depth extend of data to be modeled. In Olkaria models, geophysical models typically have a greater depth extend than production reservoir models which strictly consider measured data from drilled wells and therefore limited to drilled depths.

Properties that are depth related are easily modeled in the 3-D grid by use of petrophysical modeling function that populates the modelled property in the empty grid cells by use of user defined algorithms.

Some properties are only available for limited depths. Such data is for instance the first occurrence of minerals or well feed points. These data is therefore not up scaled into the depth grid but only visualized as point data. Although these datasets are 2-D in nature, they are modelled in a 3-D grid with capability for joint analysis with 3-dimensional properties. Figure 3 presents an example of a 3-D model with temperature property, feed points, first occurrence depth of epidote mineral and known surficial structure extended deep in the reservoir.

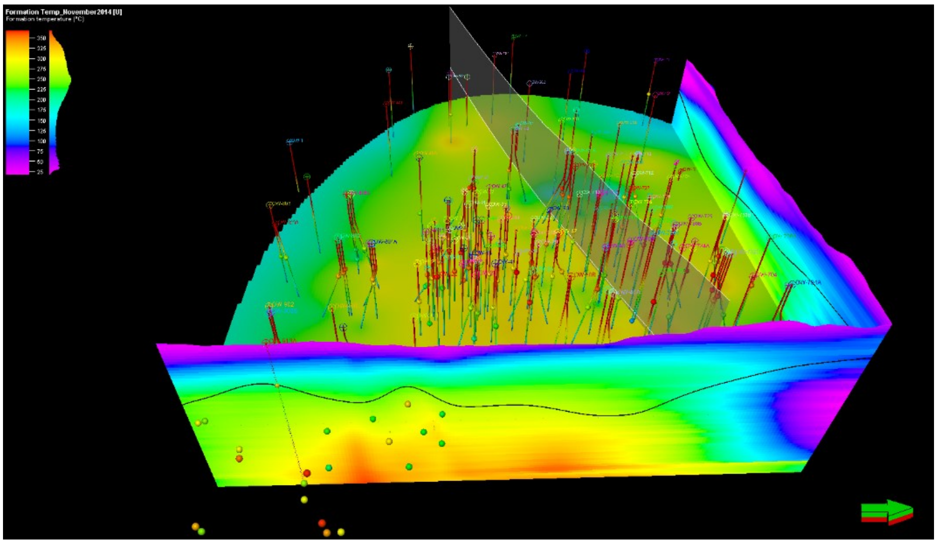

Figure 3: A 3D multi-property visualization of Olkaria reservoir Model

The ability to combine these datasets presents a valuable platform for professional communities to converse both on common observations and possible inferences that make up the process of model building. The models are therefore jointly presented in singular views with the possibility of adding or removing properties to a common viewport for interpretation or visualization. (See Figure 4)

3.2 Plane Manipulation

The orientation of a visualization can be freely adjusted to any direction either normal to the compass direction or inclined at any angle. This is a powerful tool to look for those features of the model that usually appear hidden behind other details and may never become apparent in the traditional modeling approaches.

The ability to manipulate the plane helps the interpreter to see more detail and reach far more possibilities for comparison of datasets. The tool can be used to satisfy the interests of the audience by taking different orientations relative to surface features.

Some properties of the geothermal system are also better understood with the orientation of geologic or hydrogeological features in context.

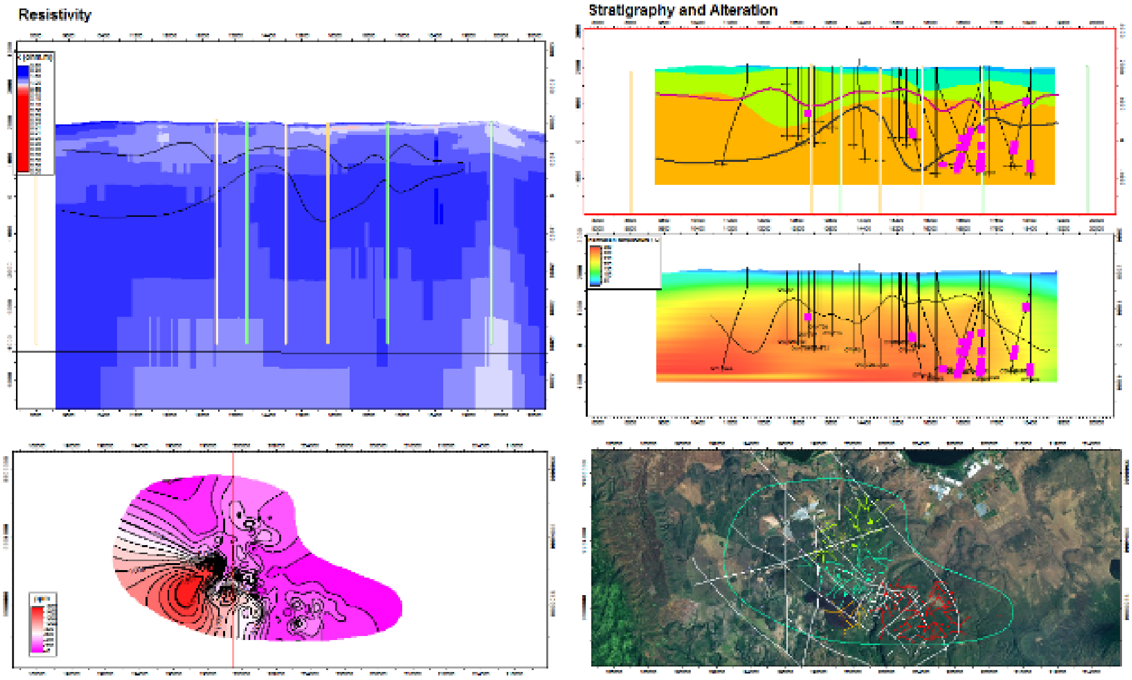

Figure 4: A 2-D Multiple VIEWPORT with resistivity, Stratigraphy, Alteration, Chloride concentration, formation temperature, feed points, wells and location map. (Saitet, 2016b)

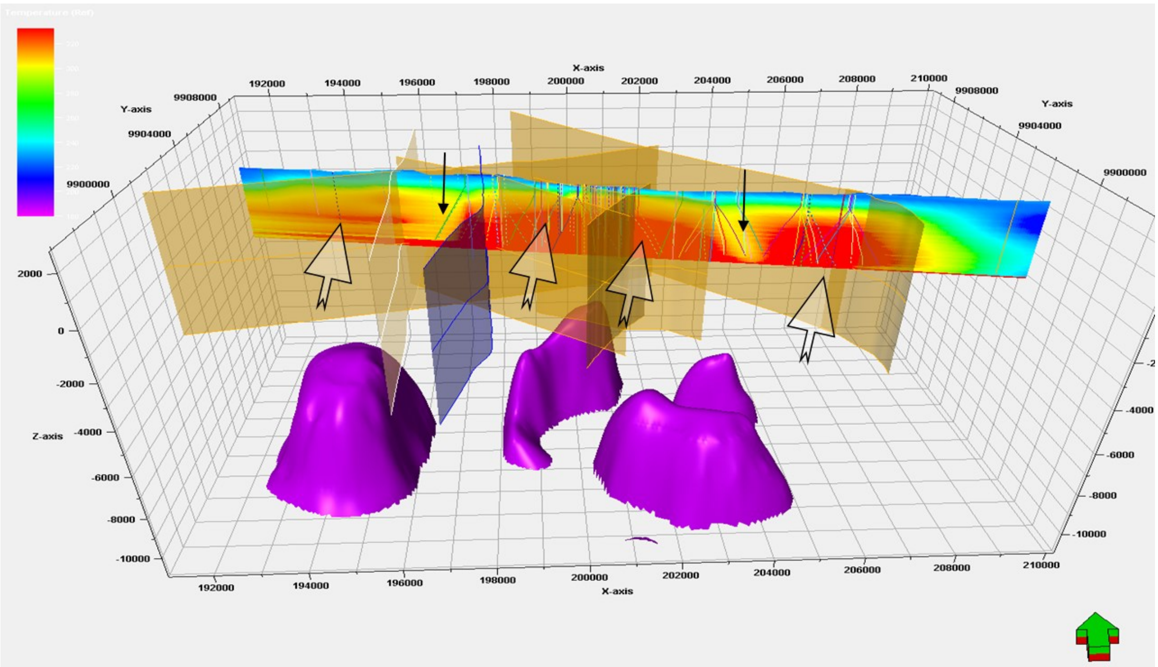

Figure 5: The present Conceptual Model of Olkaria, Saitet, 2016b.

3.3 Cross Interpretations

Interpretation of observations made by various work disciplines becomes a lot easier by using a singular platform for interpretation and visualization. (see Figure 6) To a large extend the different methodologies and datasets available to the modeler complement each other to present a single unified interpretation of the system.

With the 3-D visualization system multi-dimensional data is viewed together in a geo-referenced grid that places all the different datasets in the model with the flexibility of choosing which dataset is to be viewed with which other. This therefore provides the flexibility and adaptability required in this kind of model development.

The professional work teams are therefore well oriented to have quality cross-discipline discussions about their observations, make inferences and interpretations jointly. This is ideal for model development but so often the modelling disciplines lack an objective and principled conversation together.

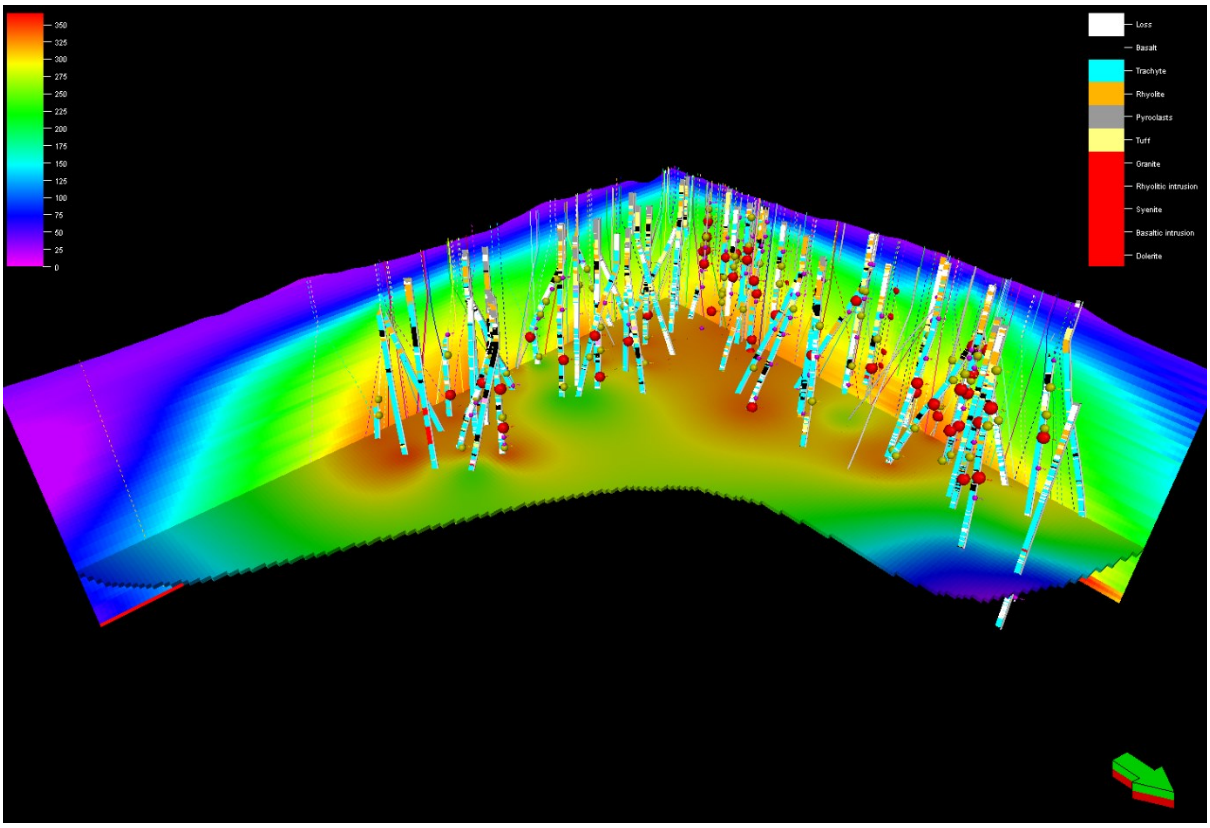

Figure 6: A 3-D Visualization of well trajectories, lithology, feed points and formation temperature

3.4 Cohesion/Teaming

The art of building cohesive professional teams is enhanced by objective and principled interactions around the same data in a way that one dataset is made to interpret another and the common deduction is adopted. Not a single discipline or set of data is then excluded or neglected.

The use of a unified single model system also enhances information sharing in a way that all different professional disciplines understand each other and appreciate the value of the respective contribution of each discipline to the joint model. This eventually leads to more buy-in of the resultant model result.

3.5 Collaborative Singular Model

A collaborative model in a singular platform is far more reliable than that made of datasets from a single methodology or discipline. These models are more reliable since they are jointly developed incorporating and unifying all the data available for a geothermal field (see Figure 4 for an example). The uncertainties from one dataset are complemented by another and the data gaps are addressed by other type of data.

The collaborative model also makes refinement of the model possible with each single data piece in the course of operating a field counting to the overall goal. Both operators and their stakeholders exploit the field with more confidence and certainty of the future.

4 THE RESULTS

4.1 Decisions

The decisions being made for exploitation or further exploration of the resources at Olkaria are costly ones, this is not only because of the general cost of drilling but also:-

a) The pace of development-there has been an accelerated drilling program for some time at Olkaria. This program involved drilling with eight rigs back to back. For drilling targets, associated infrastructural work to be done before a rig is moved to a site, data needed to be analysed faster and incorporated into the models before such decision is made. Moreover, some additional simple modelling needed to be done on a case by case to ensure the decisions being made were appropriate. Since these are team decisions, there needed to be a one stop shop for all data and interpretations readily available.
b) What is at stake is the impact of decisions to already installed plants- with 675MW already installed at various segments of the field decisions regarding additional productions wells, injection wells etc could affect the wells neighboring or those connected with the proposed wells. With these investments at stake, a dynamic model is necessary simulating the entirety of the knowledge available in the field.
c) There are multiple developers in the greater Olkaria field. Some knowledge about the operations of the other developers was necessary in making decisions about our own development strategy. Step out drilling in the unexploited areas needed to be informed in some cases with existing wells in those areas that could belong to other operators. The importance of

the model here is in the event observation were reported with little or no data shared between operators such hypothesis may be tested with an existing model.

d) The presence of a drilling contractor made the matter of drilling more complex as opposed to owner drilling. The flexibility of making decisions during drilling was limited. Logging of data in wells was only available after the well was complete. Critical data about the sites, which sometimes had more than one well planned to be drilled back to back, was only available in retrospect.

The above situations necessitated greater need for a readily available model that could be consulted during meetings, in conversations outside the formal gatherings and while teams prepared their contributions to the formal meetings. The model was ideally necessary for making each decision.

Essentially decisions made with a robust model like that of Olkaria, can be argued to be more data constrained and has higher confidence than previously.

4.2 Resource Risk

Due to the accelerated development in the recent years at Olkaria, often the teams had to confront divergent opinions from within and outside the organization regarding possible resource depletion. The opinions served as a caution to the modelling work group at Olkaria. However to achieve success, we needed to overcome the negative sentiments and strive towards our objectives. It was not easy to disregard these opinions that would come from reputable professionals. Quite frequently it was necessary to justify our actions and did not perhaps seem very convincing. Infact, we only appeared convincing when a new power plant was commissioned but then they would still caution about its sustainability.

The availability and access to all the data in our model served as the conviction to pursue our development goals. Although some decisions could still have been made without data constrained approaches, for the most part, the data led the way and teams pursued even more resolutely. It was important for us to see the model and re-look at it repeatedly to be convinced that the potential resource risks were minimal.

One functionality of the modeling platform that served us well in this area is the dynamic visualization that could be saved in a video file and be viewed repeatedly outside the model platform. This is important in the sense that general media files have broader access and do not need any expertise to view compared to the modeling platform.

4.3 Greater Cohesion

With conversations between different disciplines and correlating different datasets in resource management meetings the team work was build. People would be in social forums but yet be engaged in discussions about the observations they made at work. We believe this promoted dedicated service and spurred collaborative decisions in the various disciplines involved.

Building teams and doing it while working is the dream of every organization. The achievement of team work is therefore a good bonus for management.

4.4 Identification of Data Gaps

The 3D models presents an opportunity every time it is discussed for a review by the larger teams that would identify potential gaps that could be filled with additional data or conversations around hypothesis.

In our experience, the more the data gaps are filled and an opportunity exist to report on the updated model, the more there was buy-in of the results and a sense of ownership of the model at Olkaria. It became easier to get approvals from management for further improvements of the model and/or the modeling platform.

4.5 Management Tool

The model serves as a reservoir management tool. The frequency of update and its robustness enables its use to make decisions about the development and utilization strategies of the geothermal resource. Decisions such as locations of hot or cold injection sites, possible pressure monitoring locations and production locations are made using the model. A lot more use of the model is expected as the industry become more acquainted with the reservoir models and more time is dedicated to studying it.

It is also important to note that all available historical data regarding the properties in the model are expected to be included in the model and therefore presents a perfect forum for successions among the generations of the workforce. Although the pioneers depart, the data is left behind.

4.6 Motivation

The innovative presentation alternatives that exist in the model are in themselves a motivation to the workforce that dominates Olkaria. The majority of the workforce are in the generation that appreciates digital files either on their phones or other gadget. The messages passed would most likely be on a video clip or illustration of some graphic kind. The ability of the model to be presented in stunning graphics and video clips of different properties enhances a personal motivation to work attitude that promotes team work and builds cohesive teams. Forwarding such clips and graphics to each other on electronic media is possibly a better pass time for these teams.

On the contrary only on exceptional cases would you find such cohesive sharing of an old type-set report or hand sketch of Olkaria being shared and discussed. Even the 2D graphics of the last decade cannot thrill that much.

4.7 Culture Change

The advancements in modeling have brought about forums where observations and findings are discussed equally with both the veterans and novices being on the same understanding. No technical jargon is hidden in some plot or number as it used to be with separate models for each discipline. It is presented in clear and legible graphic that is understandable across the disciplines.

The more senior colleagues have an opportunity to create a repository in the model with the historical data usually only in their minds and make it accessible to the emerging generations.

The model platform is therefore inspiring a culture change.

4.8 Retrospective audit of quality of decisions

One possibility in the present model is the ability to audit the quality of resource development decisions that were made earlier after data is availed and modelled. There are several possibilities that the model can audit. Below are some sample of potential audit queries that can be answered:-

a. In drilling- what type of drilling contract to enter into including favorable conditions that mitigate resource risk, how fast to drill either back to back or give time for investigations? How many wells to contract out in a given field segment?

b. Well siting-Was it a good idea to step out further from the known production area? What is the optimal step out distance from known production wells? Does the established structures constrain how far to step out from the field?

c. Structural- is Oloolbutot fault really a barrier between production fields? Could the barrier be open at depth? What is the extent of the open fractures at the drilled areas? Does the gorge fault play any role in separating different upflows regions? What causes the different upflow regions at Olkaria?

d. Permeability-Does the permeability extend deeper than conventional drilling depths? What is the contribution of pore vs structure permeability in different field sectors?

e. Well Productivity- why would the different field sectors have different average well productivity? Could larger production casings be more appropriate in some field sectors?

It is important to pick lessons learnt from every experience whether good or bad in geothermal development. More importantly documenting these lessons goes a long way to ensuring they are not repeated by the future generations. To ensure objective audit of decisions made, data leads the way.

4.9 3-D Print out of Model properties

The one quick win for enhancing the impact of the current model is to avail periodic 3-D print-outs for the model properties like permeability, temperature, pressure, feed points etc that come handy in making decisions regarding well targeting and utilization. The ability to visualize a solid 3-D model would greatly enhance the effective communication of the model to the work teams, management and other stakeholders as may be necessary. Figure 7 shows a printed model of $T>240^{O}C$ with well trajectories while Figure 8 represents $T>240^{O}C$ with well trajectories and feed points. The printed out models apart from leaving a lasting impact on the audience, avail considerable clarity on spatial distribution of reservoir properties.

Considerable progress has since been made to further improve the digital limitations of the N-1 dimensionality problem. Some of these include use of filters to convey property horizons of interest and create surfaces that provide valuable information regarding targets, utilization schemes etc.

It is possible for the fourth dimension (time) to be accounted for by routine updates of the print outs in time. One may want to see the shrinking reservoir as it gets depleted or even new injections of heat if it happens within utilization timelines. More and more properties of the formation and fluid are being added into the effort to visualize in 3-D physical prints. A possible improvement that is currently being studied is the visualization of predictive models being outputs of numerical simulations at given time steps. This provides a better comprehension of reservoir response to production

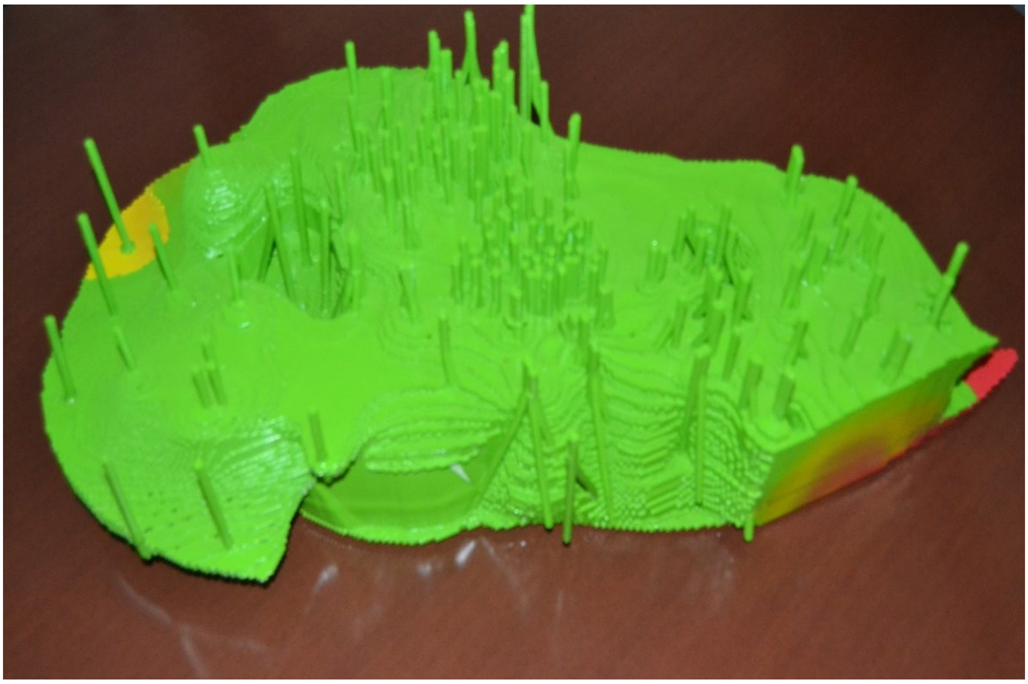

Figure 7: Digital 3D Printed Temperature Model of Olkaria reservoir top

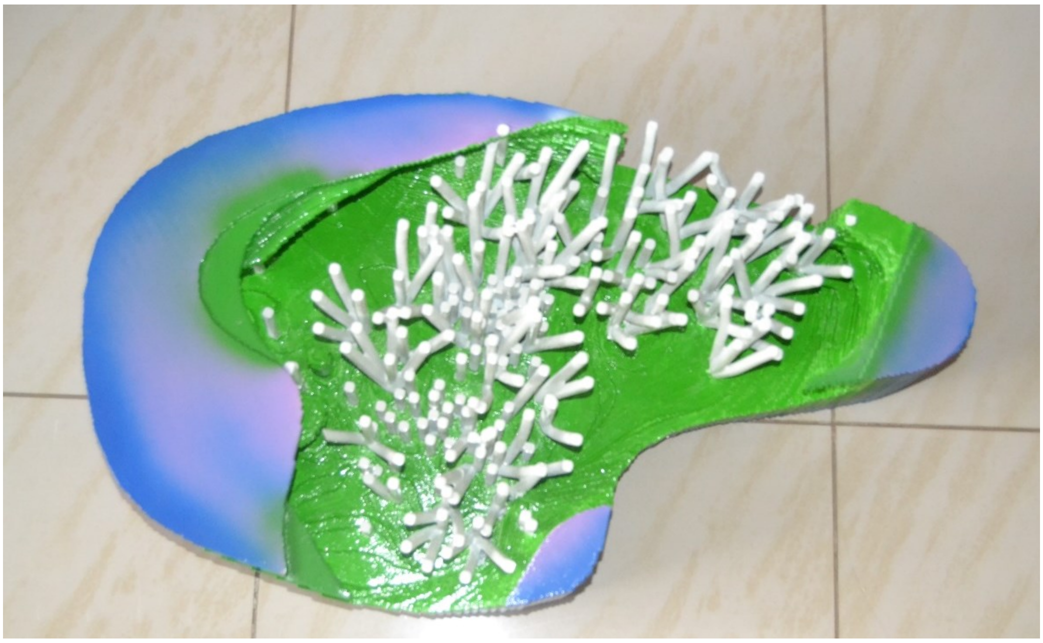

Figure 8: Digital 3D Printed Temperature Model of Olkaria reservoir

REFERENCES

WestJec, 2009: Olkaria Optimization Study (Phase2). Final Analysis Report.

Saitet et. al., 2016a: The Conceptual Model of Olkaria. KenGen internal report. 141pp.

Saitet., 2016b: Update of the Conceptual Model of Olkaria geothermal system. Geothermal Resource Council Transactions, 2016.